Can Preschoolers Profit from a Teachable Agent Based Play-and-Learn Game in Mathematics?

Anton Axelsson, Erik Anderberg, and Magnus Haake

Lund University Cognitive Science, Sweden
{Anton.Axelsson.287,Erik.Anderberg.114}@student.lu.se,
Magnus.Haake@lucs.lu.se

Abstract. A large number of studies carried out on pupils aged 8–14 have shown that teachable agent (TA) based games are beneficial for learning. The present pioneering study aimed to initiate research looking at whether TA based games can be used as far down as preschool age. Around the age of four, theory of mind (ToM) is under development and it is not unlikely that a fully developed ToM is necessary to benefit from a TA's socially engaging characteristics. 10 preschool children participated in an experiment of playing a mathematics game. The participants playing a TA-version of the game engaged socially with the TA and were not disturbed by his presence. Thus, this study unveils exciting possibilities for further research of the hypothesised educational benefits in store for preschoolers with regard to play-and-learn games employing TAs.

Keywords: teachable agent, theory of mind, preschoolers, learning by teaching.

1 Introduction

The use of digital equipment has recently made its way into the preschool curriculum. When introducing computers it is vital that we make the best use of them; this calls for innovative software. Lately, much research has gone into what is called *teachable agents*. A teachable agent (TA) can be described as an autonomous, digital student in educational software, where the idea is that the pupil takes the role as *teacher* in order to tutor the TA. This is a modern approach to the framework known as *learning by teaching* [1–3]. This role switching encourages the pupil to take responsibility for someone else's learning [4]. Thus, the pupil learns in order to teach. The main question posed in this paper is whether this pedagogical approach can be used for preschool children as well.

2 Background and Research Aims

It has been shown that teaching others is in fact a very efficient way for a *teacher* to learn [5–8]. Among the underlying mechanisms we find (i) an increased effort in spent time and depth of analysis compared to those who learn for themselves [1, 4, 9]; (ii) that teaching involves an externalisation of one's thoughts and ways of reasoning, which together with questions from the tutee can lead to discoveries of gaps and vagueness in one's own knowledge, that can accordingly be revised and developed [10, 11]; (iii) that

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so called *self-efficacy beliefs* [12], the belief in one's own competence within a given domain, can be positively affected: "I am someone who can teach X".

Some additional advantages of using a *digital* version of learning by teaching over a *non-digital* are: (i) that all pupils can be teachers, including those that are not naturally inclined to take such a role; (ii) that the teaching pupil and tutee can be matched to one-another ensuring an adequate challenge for the pupil; (iii) that no actual tutee will suffer from a poor teacher.

Numerous studies have shown that TA-based software can be powerful in terms of learning outcomes. It has been shown for 8- to 9-year-olds [13, 14]; for 10- to 12-year-olds [15–17] and for 12- to 14-year-olds [4, 18]. Hitherto, no studies have been carried out with pupils younger than 8 years old. The purpose of the pioneering study presented in this paper was to investigate whether the benefits of TA-based games can be extended down to children of preschool age, more specifically, 3- to 5-year-olds.

2.1 Understanding a Teachable Agent

In order to fully understand the concept of teaching someone else, one has to understand that others do not know exactly what I know because they possess a mind, knowledge, and feelings of their own. In other words, one has to have what is often referred to as a *theory of mind* (ToM). Research on the development of children's ToM, or mentalising abilities, begun in the early 1980s and is today one of the most active and fastest growing areas of research within cognitive developmental psychology [19].

The most standardised way of measuring ToM is looking at a persons understanding that others can possess an incorrect or false belief. Clements and Perner [20] showed that some children, although they did not fully pass the false belief tasks, did seem to have an implicit understanding of false beliefs. This finding was later corroborated by Garnham and Perner [21]. This suggests that there are different levels in the development of ToM. At the age of six, all normally developing children have a fully developed ToM, which they can explicitly verbalise.

Metacognition is paid much attention to within the learning sciences. It has an interesting relation with ToM in aspects such as knowledge about one's memory and one's abilities to handle information, problem solving, and learning strategies; one's ability to judge what is easy or difficult to learn, and so forth [22, 23]. Developmental links between early ToM and subsequent metacognitive knowledge have been shown [24].

2.2 Attending to a Teachable Agent

A suggested pedagogical benefit of TA-based games is that they support and stimulate not only problem solving and learning, but also *reflection* on problem solving and learning. This kind of metacognition is usually demanding when one is solving problems on one's own because one is required to both solve a problem, as well as monitor the problem solving. However, this dual task demand can be alleviated by monitoring *somebody else* solving a problem. Thus, one can apply the monitoring process to somebody else's thinking [16]. With teachable agents, it is the teachable agent that is doing the problem solving, which potentially frees up resources for the child's own metacognition.

In order for metacognition to occur in the interaction with a TA, the pupil of course has to really attend to the TA's problem solving and acting. Results from studies with primary school children indicate that they do indeed pay close attention to their teachable agents. This occurs both when they are required to correct or guide their TA, and in the situation where the TA is trying to solve tasks on its own and the pupil cannot interfere. For instance, Lindström and colleagues [25] report a study where 8- to 10-year-olds played a TA-based mathematics game. A rich set of spontaneous utterances from pupils watching their TAs play on their own testify to their attention to their TAs.

2.3 Engaging with a Teachable Agent

Another observation from studies with primary school children is that they show signs of high engagement in terms of emotional utterances and facial as well as gestural excitement when playing TA-based games. Chase and her colleagues [4] conducted a systematic comparison with 10-year-olds, where one group played a TA-based game and another group played the same game without a TA. When a mistake was made, the pupils in the TA-group were significantly more inclined to display affect and engagement than the pupils in the non-TA-group.

2.4 Purpose of Study

At present, there is no data and no studies on children below 8 years of age playing educational games with TAs. Thus, the question is whether benefits from TA-based games can be evidenced already for 3- to 5-year-olds or not. A possible hypothesis is that metacognition, directed to someone else, is only possible for a child that has a sufficiently mature ToM. But in principle it is an open question, and with this study we intend to initiate a first step towards answering it. The present study investigated the interaction between preschoolers, aged 4–5, and a TA. The study explored how the children would respond to a TA-based learning game, and in particular (i) their understanding of a TA in relation to their ToM; (ii) their inclination to attend to a TA; (iii) their engagement with a TA.

3 The System: Rationales for the Game

We chose early mathematics as the learning domain for our TA-game, primarily because we have experience with research and development of TA-based games in this domain for primary school children [13, 14, 18], but also because there are educational arguments, such as the need for teaching rudimentary mathematics early.

One of the key concepts in the area of mathematics for young children is *number sense*. This concept refers to an understanding of the meaning of numbers and an ability to make comparisons, as well as showing proof of fluency with numbers [26], together with an understanding that they relate to quantities [27]. Basic number sense usually emerges in children through social interaction with parents and siblings. If it does not emerge, or if children do not develop it sufficiently during their time at preschool, difficulties in understanding more complex mathematics will most likely occur once the

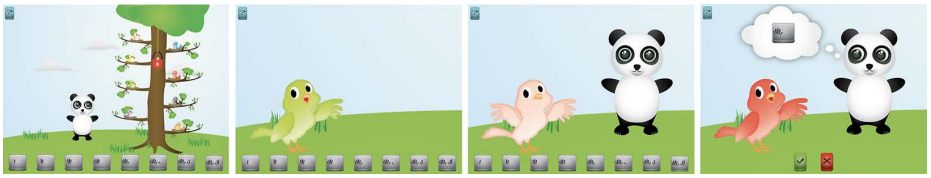

Fig. 1. Four screen shots of the game with the TA. Pictures 2–4 illustrates the three game modes: self-playing, TA-watching, and TA-playing.

child starts primary school (see e.g., [28, 29]). Number Sense can be taught [27] and for children who have not been exposed to numerical reasoning at home, formal training of Number Sense is essential [30].

3.1 The Game Design

The game used in this study revolves around chicks that fall out of their nests and need help to get back up. One chick at a time holds up a number of feathers representing the branch it lives on. The player's task is to match this number on the keypad of a lift. The idea behind using a lift is that it represents a vertical number line; it gives a good representation of parts of the whole — branches as floors — and higher numbers are further up. It is important to use concepts familiar to the child [27, 31], and lifts are common features with mathematical properties in our society. The game design is depicted in Fig. 1.

The game can be played with or without a TA. In the former, after three rounds of helping chicks, a TA (a panda named Panders) is introduced and observes the player's actions. After another three rounds the TA takes over and the player now guides the TA, correcting him if not agreeing with him. Thus, there are three modes: (i) self-playing, (ii) TA-watching, and (iii) TA-playing (see Fig. 1). If playing without the TA, the player iterates nine rounds of self-playing.

4 Method

4.1 Participants, Design and Measurements

Ten children age 4;1 to 5;2 from a nursery in Southern Sweden participated. A between subjects design was adopted with TA as an independent variable in order to compare: (i) children's inclination to concentrate when playing the game with a TA compared to without a TA, and (ii) their engagement with the game with a TA compared to without a TA. In other words, five children played with the TA and five children played without the TA. Because we were interested in whether a child's ToM would affect her understanding of what a TA is, we strived for homogeneity between the two conditions with respect to participants' ToM as well as gender and age. The variables measured and compared between the two conditions were:

(i) Engagement with the game: how involved the participants appeared to be in playing the game, as manifested through pointing, laughing, an excited tone of voice, and so forth. The opposite would be a participant appearing to be bored by the game, as manifested through sighing, looking away, not saying anything, and so forth.
(ii) Attention to the game: how focused the participants appeared to be on the task at hand, as manifested through signs of absorption in thought, such as starring, not looking away from the screen, wide open mouth, and so forth. The opposite would be a participant who is perceived as engaging in activities irrelevant to the game, as manifested through, for example, attending to things away from the screen.

For the group of children that played the game with a TA, further analysis of their verbal and non-verbal behaviour during the study session was undertaken in order to provide data for the third research question posed in the study: How do children of this age understand and interpret a teachable agent, and does it relate to their ToM?

When playing the game the participants were filmed with an unobtrusive web camera situated above the experiment laptop screen. All mouse events during game play were logged, and audio was captured through the laptop's built-in microphone.

4.2 Procedure

The nursery teacher selected children who fitted the age requirement (3–5) that were not occupied in other activities and who were willing to participate. She escorted them one by one to a secluded part of the nursery where the experiment took place. Before playing the game, a pre-test for screening ToM was conducted. The pre-test was in the form of an adapted Sally-Anne test, devised for testing false belief [32]. To pass the test, the participants would first have to point at the correct box, and also give a coherent account for their choice.

Before starting the game, brief assessment on the participants' counting skills were also carried out. The experiment leader held up eight fingers and asked the children to tell her how many fingers she held up. Those who struggled with counting past five were assigned to play the game with six floors. Those who were able to provide an answer with more ease were assigned eight floors. The rationale behind this is that the focus of this study is on participants engagement with and understanding of a TA and not on mathematical skills. Thus we wanted to avoid that participants would feel discouraged by the level of difficulty. Four children ended up playing with six floors and six children played with eight floors. After the pre-experiment tests, the participant was assigned to play the game either with the TA or without. A balancing sheet was utilised to maintain homogenous groups with respect to the participants' age, gender, and performance on the false belief task.

When a participant finished the game, the preschool teacher was called back into the room and the child was asked to explain to her what the game was about. Those who played with the TA were also asked to explain its role in the game. One of the experimenters noted down the answers with pen and paper. The experiment took on average 11 minutes to complete.

4.3 Coding and Analysis

Each video of the participants playing the game was split into three clips. Each clip consisted of three game rounds. Thus, for participants playing with the TA, the clips matched the three game modes. The resulting 30 clips were muted and randomly distributed between the two experimenters, 15 clips for each experimenter, now acting as coders. All 30 mute clips were also given to two other coders who had never seen any of the participants before. The rationale behind this was that no coder should be able to tell how far a participant had progressed in the game, and also to make it more difficult for the coders to recognise whether a participant was playing with a TA or not. The participants were rated on attention and engagement on a 7-point category scale, where 1 represented fully unattentive/unengaged respectively, and 7 represented fully attentive/engaged respectively.

After this analysis had been completed, the five full-length videos with sound of participants playing with the TA was analysed. All comments and gestures associated with the TA were transcribed.

5 Results

5.1 Understanding of the TA

Participant 1, aged 4;5, pointed correctly in the false belief test (FBT) but could not give an adequate motivation for her choice. She was good at counting and was therefore assigned to play the game with eight floors. When playing the game, she watched very concentrated as the TA introduced himself. Twice during game play, she commented on the TA's suggestions. When the TA asked: "Am I thinking correctly?" the first time she responded: "No he isn't", and the second time she said: "No, it was three in that picture, but the chick is showing two". Once when the TA asked her to show him which button he should have chosen, she pressed the correct button whilst telling him: "That little button". To the post-test question regarding the role of the TA, her answer was that she did not remember.

Participant 2, aged 5;2, did not pass the FBT. She had trouble counting and therefore played the game with six floors. When the TA was introduced, she smiled a lot. Whilst playing with him she was very reluctant to correct him and the experiment leader had to encourage her. After checking the TA's choice, she lit up with a smile and said: "He was correct". To the post-test question of the role of the TA, she responded: "You were supposed to help him".

Participant 5, aged 5;1, passed the FBT and his answer implied that he found the control question silly. He had no trouble counting and played the game with 8 floors. He focused when the TA introduced himself, but paid very little attention to him thereafter and managed to play the game with ease. To the post-test question of the role of the TA, he answered: "Panders was there to help".

Participant 7, aged 4;10, passed the FBT. She counted with ease, and was assigned to play with 8 floors. She said nothing during game play but looked several times at the experimenters for confirmation. To the post-test question of the role of the TA, she answered: "The panda was thinking right or wrong".

Participant 9, aged 4;1, did not pass the FBT. He struggled counting above the number five, and was assigned to play the game with 6 floors. He seemed very reluctant to correct the TA. He continuously pressed the "correct" button in the TA mode, even when the TA had guessed incorrectly, and even when the chick only wanted to go to the third floor. Conversely, he made no errors prior to the TA mode even when presented with the numbers 5 or 6. To the post-test question of the role of the TA, he answered: "The panda is watching".

5.2 Attention and Engagement

When analysing inter-rater reliability for the 30 clips, Spearman's rho revealed that consensus among the coders concerning attention was too low to draw any reliable conclusions. This variable was therefore excluded from analysis. We intend to further investigate the focused attention on a TA with regards to preschoolers, and this will be discussed briefly in Section 6.1.

Regarding engagement, Spearman's rho revealed a significant correlation of inter-rater reliability ($p < 0.01$). From observing the children during the experiment, it was noted that at least three of the five participants were more motivated to play once the TA was introduced. However, this did not surface in an analysis of covariance, which revealed that there were no significant differences in encoded engagement of participants playing with or without a TA.

The qualitative analysis of the video recordings revealed that participants, regardless of condition, in general were pleased with playing the game and seemed to enjoy it. There were a lot of laughters and surprised faces during game play. Though, participant 5 got quite bored with the game and was not shy to make this clear when asked. However, this was one of the oldest participants who, as mentioned above, both counted and passed the FBT with ease.

6 Discussion

This study represents a pioneering examination of how 4 to 5 years old children respond to a teachable agent based educational game. The results showed that engagement — the participants involvement in the game — was evident both with and without the TA. This gives us an indication that the game is in itself engaging. More important, however, is the observation that the children seemed quite at ease in interacting with the TA, and the TA did not impede on engagement to the game and seemed not to be obtrusive.

Unfortunately, the coders could not agree on the participants' inclination to attend to the game. However, the answers the children gave of the TA's role indicated that they indeed had focused on the TA's actions and speech. All of the children either used terms that the TA himself used throughout the game when answering the question as to what they thought the role of the TA was, or responded to him verbally when he asked questions. Judging from the way the participants acted with or commented on the TA, it was also apparent that they did interpret him as a social character that they were supposed to help, or as someone who was there to learn. Especially participant 1 treated the TA as a social entity by promptly responding verbally to his questions.

The results seem to indicate that children can at least engage with social characters without a fully developed ToM. And it was evident that the participants had no trouble playing the game with or without a TA because they were able to help the chicks both by playing alone, and with the TA. Two participants completely failed the false belief task and they were both reluctant to correct the TA. One participant had to be encouraged to give it a try and was successful, the other just kept confirming that the TA was correct when he clearly was not. This participant did have some trouble counting and it could be argued that this was the cause. However, he confirmed the TA even when the TA was incorrect in a round involving the number 3, a task he should have been able to solve considering that he made no errors prior to the TA mode even when presented with numbers as high as 5 or 6. It is tempting to conclude that these two participants' reluctance to correct the TA would be due to an underdeveloped ToM. However, a more extensive assessment of the participants stage in development of ToM would have had to be undertaken before any conclusion could be drawn. An alternative explanation could be that, at least one of the participants lack in executive functions and could therefore not inhibit his urge to press the green confirmation button when the TA was incorrect. We plan to further investigate this (see Section 6.1).

There are three important factors revealed through this study: (i) preschool children are not disturbed by the presence of a teachable agent; (ii) preschool children are able to pay attention to a teachable agent; (iii) it is possible for preschool children to engage in a socio-cognitive interaction with social characters regardless of a fully developed ToM.

6.1 Implications and Future Research

Being a pioneering study with a limited number of participants the study clearly calls for continued research of the potential benefits of using TAs in pedagogical games for preschoolers. A longitudinal study of the learning effects of using TAs with preschoolers is obviously critical. However, such a study is very costly in terms of time and resources, and it is therefore essential to make sure that preschoolers are able to grasp the concept of a TA. An upcoming study will investigate TA-based games with respect to focus of attention among preschoolers. We will study how well preschoolers can inhibit distractions in order to keep focused on the TA, and its relation to the development of ToM and executive functions.

In a larger context, the questions under investigation are crucial. It is well established that metacognitive abilities is a key factor for children's success in their development as learners [33–36], and it is therefore important to further investigate young children in this respect.

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